Research and Development towards Improved Operational Prediction of Tropical Cyclone Behaviour and Associated Significant Weather

Noel E. Davidson
Bureau of Meteorology Research Centre,
PO Box 1289K, Melbourne, 3001. Australia
Ph : (+ 613)-9669-4416; Fax : (+ 613)-9669-4660; Email : n.davidson@bom.gov.au

Persons Visited
(a) Drs. P. Merilees, R. Hodur, Chi-Sann Liou, J.Goerss, J. Hawkins, M. Peng, S. Burk, J. Doyle, T. Holt, K. Sashegyi, J. Nachamkin.
Naval Research Laboratory, Monterey, CA, 93943-5502
Phone : (831) 656-4721; Fax : (831) 656-4314; Email : liou@nrlmry.navy.mil

(b) Prof. R. Elsberry, Drs. L. Carr, M. Boothe, P. Harr, E. Ritchie.
Naval Postgraduate School, Monterey, CA, 93943-5114
Email : elsberry@met.nps.navy.mil

Award Number: N00014-01-14060

LONG-TERM GOALS

A major long-term goal of both BMRC and NRL is improved operational prediction of Tropical Cyclone (TC) behaviour (track, intensity and genesis), and associated significant weather. An additional aim is to improve understanding of the processes that determine these characteristics. A major outcome of the visit was the development of plans aimed at achieving these goals through collaborative research on :

(i) improved methods of data assimilation and TC initialisation,
(ii) application of explicit cloud microphysics,
and (iii) prediction and diagnostic studies of TC genesis

OBJECTIVES

(a) Collaboration

1. To establish collaboration on TC research between BMRC and NRL.
2. To exchange recent experiences with operational high resolution TC prediction over the northwest Pacific.
3. To define research projects of mutual benefit that would involve both strategic and applied research and draw on the diverse skills, systems and data sets available at BMRC and NRL.
4. To develop plans for a NICOP research proposal.

(b) Projects

The first project objective is to develop techniques to (numerically) build a high resolution TC

vortex, consistent with observed structure (intensity, size, depth, past motion, inner core, convective and wind asymmetries), that is balanced, and suitable as input to a numerical prediction model for track and intensity forecasting.

The second project objective is to apply and compare prognostic cloud schemes available at NRL and BMRC on TC events of common interest, and to evaluate and refine their performance for prediction of TC behaviour and associated significant weather.

The third project objective is to investigate TC genesis using some of the above techniques with the aims of better understanding the processes and defining the requirements for improved operational prediction.

APPROACH

Operational forecasts from the Australian Bureau of Meteorology=s Tropical Cyclone Limited Area Prediction System, TC-LAPS (Davidson and Weber, 2000), have verified well, based on standard measures of skill. The sophisticated vortex specification and initialisation using model dynamics and satellite cloud imagery are unique components, which provide the basis for track *and* intensity forecasts. However improvements are possible, particularly with respect to defining wind and convective asymmetries, outer spiral cloud bands, neighbouring mesoscale convective systems, and balanced vortex structure. The starting point for objective (i) will be the current BMRC operational method, but with enhancements to include (a) processed satellite cloud imagery at much higher resolution, and (b) hourly satellite-diagnosed rain rate data from NRL (Hawkins et al., 2001).

Recently-implemented within the BMRC=s limited area modeling framework has been an Explicit Microphysics Scheme (EMS), often referred to as a prognostic cloud scheme. The scheme has shown, in case studies, considerable skill in the prediction of significant weather (rain, hail, snow, fog, low cloud and severe storms - including diagnosed lightning) not necessarily associated with tropical cyclones (Dare et al, 2001). Additionally a limited number of experiments suggest positive impact on the prediction of TC behaviour (track, intensity and genesis). Testing and evaluation of the EMS and the equivalent explicit scheme in NRL=s Coupled Ocean/Atmosphere Mesoscale Prediction System, COAMPS (Hodur, 1997) on selected TC events will be the initial approach for objective (ii). Issues to be addressed include: (i) refinements to the representation of conversions between water species, (ii) initialisation of water species, (iii) coupling with a convective parameterisation, (iv) interfacing to the radiation scheme, and (v) validation of microphysical cloud structures using observational data, possibly from the new joint US/Australian Atmospheric Radiation Measurement (ARM) site in Darwin.

Application of the above techniques to the difficult problem of forecasting TC genesis is particularly appropriate and easily justified on scientific grounds. Observational evidence suggests that many storms develop first through midlevels, and then extend upwards and downwards. When the vortex eventually reaches the surface, rapid strengthening and a burst in convective activity occurs. To adequately simulate the midlevel development, will require the use of an explicit moisture scheme to represent the dynamical and radiative properties of stratiform cloud decks associated with mesoscale convective systems. The approach to the problem will be

based upon the techniques developed for objectives (i) and (ii) and will involve the use of additional, newly-available data (scatterometer and rainfall), advanced assimilation techniques, and application of the explicit cloud microphysics scheme during assimilation and prediction. The objective draws upon recent conceptual models of genesis, and so is unique and underpinned by observational and theoretical studies.

Central to the success of the collaboration are intercomparisons of initial conditions and forecasts for mesoscale TC events. These collaborative intercomparisons will (a) identify the strengths and weaknesses of each individual system and so benefit both BMRC and NRL, and (b) ensure that new results are robust and mostly independent of numerical systems. Plans have been developed for exchange of data sets and relevant computer codes as necessary.

The project involves both strategic and applied research and will draw on the diverse expertise, systems and data sets available at BMRC and NRL. For this reason the project is futuristic, will have major impact on research and operations, is unique, and may only be achievable at institutions like BMRC and NRL.

TRAVEL COMPLETED

Table 1. Summary of visits conducted under the VSP.

Person Visited	**Position**	**Institution**	**Location**	**Scientific/ Technical Purpose**	**Dates (mm/dd/yy)**
R. Hodur	Branch Head	NRL	Monterey	Modelling	4/23/01
C.-S Liou	Section Head	NRL	Monterey	Modelling& Collabor-ation	4/23/01
J. Goerss	Scientist	NRL	Monterey	TC Forecasting	4/23/01
J. Hawkins	Meteor-ologist	NRL	Monterey	Satellite Applications	4/23/01
M. Peng	Scientist	NRL	Monterey	Modelling	4/23/01
S. Burk	Section Head	NRL	Monterey	Modelling	4/24/01
J. Doyle	Scientist	NRL	Monterey	Modelling	4/24/01
T. Holt	Scientist	NRL	Monterey	Operational Procedures	4/24/01
K. Sashegyi	Scientist	NRL	Monterey	Data Assimilation	4/24/01

J.Nachamkin	Scientist	NRL	Monterey	Verification	4/24/01
R. Elsberry	Professor	NPS	Monterey	TC Research	4/25/01
L. Carr	Assoc. Prof.,	NPS	Monterey	TC Forecasting	4/25/01
M. Boothe	Meteor-ologist	NPS	Monterey	TC Forecasting	4/25/01
P. Harr	Assoc. Prof.	NPS	Monterey	TC Behaviour	4/25/01
E. Ritchie	Assoc. Prof.	NPS	Monterey	TC Behaviour	4/25/01

RESULTS

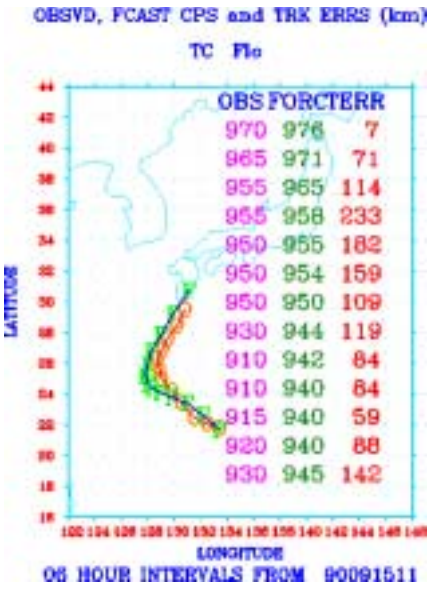
Visit to NRL, Monterey : (a) A seminar on the BMRC operational, high resolution Tropical Cyclone Limited Area Prediction System, TC-LAPS, was presented. The talk focused on : (i) methodology and system description, (ii) operational results, (iii) systematic errors, and (iv) future developments. (b) From this seminar emerged extensive discussions on the most productive directions of research that would be of mutual benefit to NRL and BMRC. The priorities included: TC vortex initialisation, use of explicit microphysics schemes, and diagnosis and prediction of Tropical Cyclone formation. (c) Initial plans were formulated to collaboratively investigate these issues. (d) Recommendations were made for exchange of data sets and software, rapid communication of results, and exchange visits. (e) A NICOP request for funding and NICOP proposal are in preparation.

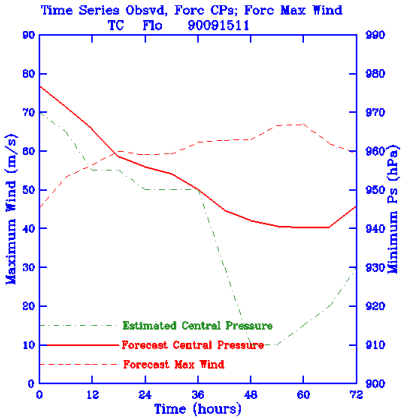
Visit to NPS, Monterey : (a) Initial discussion focused on the NPS=s Systematic Approach to TC forecasting and how TC-LAPS could be incorporated into the NPS multi-model ensemble prediction system. (b) Extensive discussions were made on major TC forecast issues including genesis, intensification and extra-tropical transition. (c) One outcome from this interaction has been the application of the BMRC TC-LAPS to the prediction (and eventual diagnosis) of the intensification and recurvature of Typhoon Flo (Titley and Elsberry, 2000) from the ONR Tropical Cyclone Field Experiment, TCM-90 (Tropical Cyclone Motion - 1990). Early results with the latest research version of TC-LAPS are shown in the figures below. The diagrams show observed and simulated tracks and intensities for 72 hour forecasts. The quality of the forecasts for both track and intensity provide encouragement for improved operational prediction. They also offer the possibility of understanding the underlying processes behind the recurvature and intensification.

IMPACT/APPLICATIONS

(a) Closer collaboration stands to benefit both the US and Australian groups. Exchange of knowledge and experience on data assimilation, vortex initialisation for track and intensity forecasting, application of explicit microphysics, and research into TC formation will advance

science nationally and internationally.
(b) Sharing expertise on initialisation and model requirements will enhance the capabilities of both scientific institutions. US and Australian groups are working towards similar goals, and thus the collaboration is a natural one, with numerous mutual benefits. In the longer term, we foreshadow that the developments for TC applications will be equally applicable to the more general problem of significant weather forecasting.
(c) Links with operations and research in the US Navy have already been established via requests from JTWC and NPS for output from the BMRC operational Tropical Limited Area Prediction System (TLAPS) and from TC-LAPS. The data have been made available for real time evaluation and possible application in the NPS multi-model ensemble prediction system for tropical cyclones.





TRANSITIONS

(a) Improved operational TC forecasts will be of benefit to both naval and civilian communities worldwide. This can be achieved through improvements in initialisation and physical parameterisations in high resolution TC models. Accurate forecasts will assist with planning, reduce costs, enhance the success of military operations, and provide detailed information for both military and civilian authorities during TC events.
(b) Well-organised, structured and maintained models, which have demonstrated their worth in operations (TC-LAPS, COAMPS) will be of great benefit to the academic and non-academic communities. This benefit can be enhanced via collaborative intercomparisons to identify the strengths and weaknesses of each individual system.
(c) A main focus of the proposed collaboration is operational implementation of fully validated research developments. Transitions will occur as demonstrated impacts are obtained in research mode.

RELATED PROJECTS

Ongoing support and enhancements to all system components, via a unified approach to limited area modeling, means that there are numerous related projects : the most significant of these are (i) the development of a 3-D variational analysis (3DVAR) at NRL, and a GENeralised Statistical Interpolation (GenSI) at BMRC, (ii) use of new data sources in the objective analysis, (iii) enhancements to the boundary layer and cumulus parameterisations, (iv) refinements to and ongoing evaluation of the explicit microphysics scheme via objective rainfall verification, (v) improvements to the vortex specification in TC-LAPS, particularly for weak or just-named storms, and (vi) diagnostic studies of TC behaviour.
Collaborative studies based on TC-LAPS with Drs. H. Weber, L. Shapiro and D. Moller of the University of Munich, on enhancements to the vortex specification, and model diagnostics of TC intensification are ongoing.

SUMMARY

Closer collaboration between BMRC and NRL stands to result in significant benefits for operations and research, at both institutions, and at national and international levels. Significant improvements are possible to operational forecasts of tropical cyclone behaviour and associated significant weather, by drawing upon the diverse expertise and systems available at BMRC and NRL, and building on and comparing their near state-of-the-art systems. Besides the indirect impact available from system enhancements not specifically targeting the Tropical Cyclone problem, there is preliminary but compelling evidence that large positive impact on prediction can be obtained from : (i) improved methods of vortex initialisation, (ii) application of explicit cloud microphysics, and (iii) prediction and diagnostic studies of TC genesis. In the longer term the techniques developed for TC applications will be equally applicable to the more general problem of significant weather prediction.

References :

Dare, R.A., N.E. Davidson and Y. Wang, 2001 : Prediction of rain, hail, snow, fog and low cloud with a bulk explicit microphysics scheme. *Mon. Wea. Rev.*, (to be submitted).

Davidson, N.E. and H.C. Weber, 2000: The BMRC High Resolution Tropical Cyclone Prediction System : TC-LAPS. *Mon. Wea. Rev.*, **128**, 1245-1265.

Hawkins, J.D., T.F. Lee, J. Turk, C. Sampson, J. Kent and K. Richardson, 2001 : Real-time internet distribution of satellite products for tropical cyclone reconnaissance. *Bull. Amer. Meteor. Soc.*, **82**, 567-578.

Hodur, R.M., 1997 : The Naval Research Laboratory=s Coupled Ocean/Atmosphere Mesoscale Predictions System (COAMPS). *Mon. Wea. Rev.*, **125**, 1414-1430.

Puri, K., Dietachmayer, G., Mills, G., Davidson, N., Bowen, R., Logan, L. and Leslie, L., 1998: The new BMRC Limited Area Prediction System, LAPS. *Aust. Met. Mag.*, **47**, 203-223.

Titley, D.W. and R.L. Elsberry, 2000 : Large intensity changes in tropical cyclones: A case study of supertyphoon Flo during TCM-90. *Mon. Wea. Rev.*, **128**, 3556-3573.

Wang, Y., 1999 : A triply-nested movable meash tropical cyclone model with explicit cloud microphysics - (TCM3). BMRC Research Report No. 74. Available from BMRC, PO Box 1289K, Melbourne, 3001. Australia. 81pp